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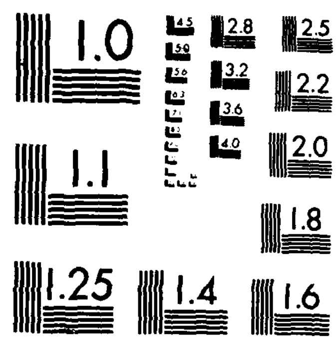

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RESEARCH AND CALIBRATE

THE LOGISTICS SUPPORT COST MODEL

OUT OF PRODUCTION FACTOR

THESIS

Stephen R. Klipfel

AFIT/GSM/LSQ/86S-11

DEPARTMENT OF THE AIR FORCE
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RESEARCH AND CALIBRATE THE LOGISTICS SUPPORT COST MODEL OUT OF PRODUCTION FACTOR

THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
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In Partial Fulfillment of the
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Master of Science in Systems Management

Stephen R. Klipfel, B.S.

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Preface

The purpose of this study was to test a factor which had become traditional in the estimation of support costs for new Air Force aircraft, missiles, and electronic systems. This study updates a heuristic, or rule of thumb, and replaces it with information computed using solid sampling and statistical techniques.

This study was based on a random sample of Air Force avionic parts. New factors were developed using univariate and multivariate statistical techniques. Although the results were a significant improvement from the use of the traditional heuristic, more work still needs to be done in this area. While the question "what is the appropriate factor" has been partially answered, answering the question "what causes the differences in the factor value" will require much more study.

The preparation of this study was not my effort alone. I would like to especially thank my faculty advisor Ms. Jane Robbins for her very helpful suggestions. I would also like to thank Mr. Roland Kankey and Dr. Jerry Hofmann for their recommendations on statistical tests and practical aspects in cost estimating. In addition, I must thank Mr. Roy Schnee for his assistance in collecting the data without which this study would have been impossible. Lastly, I would like to thank my wife Johnene for her support.

Stephen R. Klipfel

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Abstract

thesis

This ~~investigation~~ reviewed the statistical significance of the Logistics Support Cost (LSC) Model Out of Production Factor (OOPFAC) which is used to compute aircraft and missile spare parts costs during the support phase of a weapons systems life cycle. The review was composed of two major areas. First, the review computed statistics for four groups of avionic spare parts to determine if there was a single OOPFAC or if multiple OOPFACs were required for estimating. Although not totally conclusive, the results indicated that more than one OOPFAC should be used for cost estimating.

Second, the OOPFACs computed from recent data were compared using statistical tests to the original OOPFAC developed over seven years ago. The statistical tests rejected the use of the original factor, and the OOPFACs computed as part of this investigation were statistically different, by wide margins, from the original factor. As a result of this investigation, the OOPFAC should be updated in all Air Force cost estimating models to incorporate the newly computed factors.

RESEARCH AND CALIBRATE THE LOGISTICS SUPPORT COST MODEL OUT OF PRODUCTION FACTOR

I. Introduction

General Issue

Accurate estimates of the support cost of proposed Air Force weapon systems are important in deciding which systems to procure to maximize the defense capabilities of the United States. Accurate estimates are also important in deciding how to budget adequate funds to insure that the systems which are purchased are operationally ready when they are needed. The Out of Production Factor (OOPFAC) is an important part in estimating the cost of replenishment spare parts for the Air Force. The OOPFAC was first developed in 1978 and has not been revised since. Hundreds of millions of dollars in spares have been estimated using a factor which was developed over seven years ago, was based on a limited sample, has never been statistically analyzed, and has never been updated.

Specific Problem Statement

The specific problem was to determine if the concept of the OOPFAC was valid, and in the process answer the research question: "Is there a statistically significant mathematical relationship between the price of the items in the acquisition phase and the price of the same items when

they are purchased, as spare parts, in the operating phase of a weapon system's life?"

Objectives and Hypothesis

The basic objective of the thesis was to test the hypothesis that the OOPFAC exists. That is, a logical and statistically significant relationship exists between the price of an item of supply (in this case a repairable aircraft component), when it is manufactured using mass production techniques and involving large quantity purchases, and the price when it is purchased at a later point in time and manufactured, most probably, by hand in order to provide small quantities of spare parts. The purpose of this research was to test the validity of the OOPFAC concept, and if the concept were true to develop a current OOPFAC with complete statistics for use in estimating replenishment spare parts costs.

Definitions of Terms

The following terms are used frequently throughout this document and are defined here for the convenience of the reader.

The OOPFAC is the

> Out of production factor. This factor is applied to the cost of spares for each item during the steady-state year to account for anticipated increased procurement costs once production ceases. If a zero is entered the default value of 1.8 will be used [2:17].

For example, if a part costs $100 during the acquisition phase, the OOPFAC default value of 1.8 would be used to predict the cost oi the part as $180 (plus inflation adjustments) during the support phase. Specifically, for each component part being processed in the Logistics Support Cost (LSC) model, the OOPFAC is multiplied by the average unit cost of the part in the last annual acquisition phase lot. This product becomes the estimate of the unit price of the part in the support phase of the system life cycle. Total costs for the part are obtained by multiplying the unit price by the anticipated quantity to be purchased. Total parts cost for the weapon system is computed by summing the cost for each component part included in the model processing (2:33-34).

> Replenishment spare parts will include those repairable components, assemblies, or subassemblies required to resupply initial stockage or increased stockage for reasons other than support of newly fielded end items. Replenishment will include additional stockage due to increases such as usage, readiness initiatives, and redeployment of end items [23:2].

> Initial spare parts will include those repairable components, assemblies, or subassemblies required as initial stockage at all levels including the pipeline in support of newly fielded end items [23:2].

> Avionics: the development and production of electrical and electronic devices for use in aviation, esp. of electronic control systems for aircraft and airborne weapons; also; the devices so developed [8:151]

Work Breakdown Structure (WBS) is a logical method of dividing an Air Force weapon system (such as an aircraft or missile) into its constituent parts in a way such that parts with similar functions are grouped together. An example is the Weapon System Cost Retrieval System (WSCRS) WBS which divides aircraft parts into seven categories: Aircraft Accessories, Armament Accessories, Engine Accessories, Support Equipment Accessories, Avionics Instrumentation Accessories, Avionics Communication Accessories, and Avionics Navigation Accessories (3:1).

Limitations of Scope

For the purpose of this research it was not possible to review and update the OOPFAC for all types of Air Force parts. This was because the Air Force had, at the time of the study, about 165,000 repairable spare parts in its active inventory (1:GI16). These spare parts are also divided into 50 to 55 classes or types of parts which are used on aircraft or missile systems. Therefore, the research was designed to revise the factor for selected types of items and to develop an approach which can be used by other Air Force Institute of Technology (AFIT) degree candidates or by Air Force Logistic Command (AFLC) personnel to update the remaining classes of items.

The specific types of items selected for the first phase of update were avionic items. Avionic items were selected because they are most often the highest cost parts

and because many major Air Force programs now consist of modifications to avionic systems. To be consistent with other cost analysis documentation, the thesis used the defir. tion of avionic elements from the Weapon System Cost Retrie al Systems (WSCRS: H036C) Work Breakdown Structure (WBS) 3:1-2).

II. Background

General Background

The OOPFAC is a factor used in the AFLC version of the Logistics Support Cost (LSC) model to adjust for price changes between the acquisition phase of a weapon system and the operations phase (2:3). During the acquisition phase, equipment items are normally purchased in large quantities and at economical production rates. More efficient manufacturing techniques are used, set-up times are spread over larger quantities, and component parts can also be purchased by the manufacturer of the item in more price effective quantities.

During the support phase, replenishment spares are purchased at irregular intervals and often in small quantities. This does not allow the manufacturer to use the most efficient production methods as it may cost more to set up the production line than to turn out a few items using more labor intensive techniques. The result is that the spare part is likely to cost more than the original part in constant dollars (2:11,17).

The original OOPFAC was developed from a survey of prices for C-141 StarLifter avionics parts which was made in 1978 (18:1). This factor of 1.8 times the last production buy price has been used ever since for estimating the price of all types of replenishment spares.

The sample is limited both in the number of items and in their type. The sample itself was a convenience sample and was not originally collected for the development of the OOPFAC. Estimating experts (such as Mr. Henry Ring, the Chief of the Cost Analysis Division in HQ AFLC) believe the 1.8 factor needs to be revised and expanded to include other classes of items.

This belief is based on the fact that the OOPFAC is critical in estimating spares costs. For example, a 10% error in the OOPFAC would result in an error in the life cycle cost of a major weapon system such as the B-1 bomber of $200 million.

The Logistics Support Cost (LSC) model is a mathematical model used extensively in the Independent Cost Analysis (ICA) Program (2:3). The LSC is composed of a series of mathematical equations to model the Operating and Support Costs of Air Force weapon systems. Each element of cost is represented by an equation which uses the reliability and maintainability of individual aircraft recoverable spare parts as independent variables. In estimating the replenishment spares cost element, the unit price of the items being replaced is also an important independent variable, along with average time between failure and the proportion of failures which result in the item being condemned (2:24-26). The OOPFAC is a significant factor in estimating replenishment spares costs.

Many of the cost estimates developed with the LSC model, which are based on the OOPFAC, are presented to HQ United States Air Force and Office of the Secretary of Defense personnel to provide information for making production decisions on aircraft or missile systems. As a result, the OOPFAC has an important role in decisions on weapon system procurement and on expected funding levels for spare parts for new weapon systems. Therefore, it is important that the OOPFAC be as accurate as possible.

Related Studies

Only one recent study has been found which is directly related to the topic of this thesis. That study was performed by Tanya Jones while under contract to the Air Force Business Research Management Center. The study involved two parts, only one of which is relevant to the OOPFAC research.

In the relevant portion, Jones attempted to develop a nomograph, a graphic estimating method, for estimating the replacement unit price of non-repairable valves based on historical and projected information. Her research indicated that a simple nomograph was not suitable for estimating replacement valve prices. She indicated that a major problem was obtaining adequate descriptive information on the various types of valves. Her study, although it does not include a usable nomograph, suggests

that not all possibilities for estimating the prices of valves were exhausted and proposed two methods of developing an estimating relationship. The first proposal was that a separate nomograph may be required for each type of valve. The second was that the estimating relationship may be logarithmic and not linear as originally anticipated (12:4-3).

The Jones study indicates how hard it is to develop meaningful estimating relationships from the mass of Air Force data. A particular problem is the lack of clear information to divide the parts into homogeneous classes of items. This study has attempted to resolve the problem of homogeneous classes of items by using the WSCRS WBS, but differences in the level of technology will not be resolved by this approach. Also, Jones indicates that descriptive information is not available with the procurement records and matching descriptive information with the procurement histories requires engineering knowledge and more time than is available for most studies.

III. Methodology

Outline of Approach

The general method used in this thesis is divided into four major steps.

1. The existing literature on the OOPFAC was reviewed, particularly the development and use aspects of the factor. Those articles which discuss required background information and tests of the validity of the concept of the OOPFAC were incorporated into the thesis. In addition to a review of the literature, experts familiar with the development and use of the OOPFAC were interviewed to gain additional information.

2. Data was collected on the Air Force aircraft repairable spare parts which have had more than one purchase. The process used to collect the data was record analysis, as discussed in Emory as a technique of non-behaviorial observation (7:176-177). The data collection required two distinct steps. First, it was necessary to determine which spare parts had been purchased more than once. Second, the list of spare parts which had multiple purchases was used as a sampling frame and a random sample of items was collected for use in the analysis phase of the research. The data collected on the items in the sample

included the stock number (for part identification), and for every purchase of each selected part:

a) date of purchase
b) quantity purchased
c) unit price.

3. The data was analyzed using the statistical analysis package developed by the SAS Institute Inc. SAS procedures for univariate analysis (PROC UNIVARIATE), analysis of variance (PROC ANOVA), and regression analysis (PROC REG) were used to evaluate the data (21; 22). Prior to analysis the data was normalized for changes in price level using standard Air Force price deflation tables (11:3,11). Then, the data was analyzed to determine:

a) if the OOPFAC concept was valid

b) what mathematical model of the OOPFAC had the highest statistical significance

c) if the OOPFAC had the same form and estimated population means for all types of parts, or if different means were indicated for different types of parts.

4. The results of the data collection and analysis were documented. This step involved writing the thesis document itself.

Data Collection

Data was collected from the Air Force Acquisition and Due-In System (J041) for items which have had repeated purchases. The first phase of data collection used data

from the J041 product "FY85 Repetitive Buys" designated product number DAR-LOG-PMX-J85-018. This product lists all Air Force repairable aircraft parts which have had multiple purchases within the past five years. These products, one for each Air Logistics Center, provided the population which was sampled.

The sampling frame was constructed using the list of stock numbers and the Weapon System Cost Retrieval System (WSCRS) Work-breakdown Structure (WBS). The WSCRS WBS was used to determine which parts listed as having multiple purchases fall into the avionics parts categories. From each of the three WSCRS avionics WBS categories, approximately 100 items were randomly selected to form a sample for analysis (see the Data Preparation section for a summary of data requested, received and usable). These avionics categories were: 1) Instrumentation Accessories, 2) Communication Accessories, and 3) Navigation Accessories (3:1).

The actual procurement history discussed in the previous section was obtained by using the J018, On-line Procurement History System. The data itself was prepared for each stock number using the Procurement History Report (PHR) to obtain J018 Contractor Information Data System (CIDS) Procurement History Reports.

Analysis of Data

Once the procurement history was collected, standard statistical analysis techniques were used to organize the data in order to either validate the existing OOPFAC or develop a new factor to fulfill the same function. The major emphasis was to validate the concept of the OOPFAC as well as to obtain a specific factor for use in estimating.

One potential problem with the OOPFAC as it was originally formulated was that many causes (independent variables) were all explained as a single factor. For purposes of analysis it was necessary to consider methods of estimating the OOPFAC from other variables.

The original OOPFAC was fixed for all types of items, quantities of purchase, and gap between purchases. These are all potentially strong independent variables which could be used to predict the OOPFAC. These variables are all available or computable from available outputs of the LSC model; therefore, it would be easy to have the LSC model estimate using a specific OOPFAC for each type of item if it were possible to develop an estimating approach.

Based on the hypothesis that the OOPFAC could be estimated, five models were considered for investigation. Although other models are possible, these five were considered to be the most likely to provide logical and statistically significant representations of the data.

The first model was the two variable linear regression model. The independent variable was the price of the item during acquisition. The model would look like equation (1).

$$Y = a + bX, \tag{1}$$

Where:

Y = the OOPFAC,
a = the intercept,
b = the slope,
X = the independent variable.

The second model was the multiple variable linear regression model, with type of item, quantities purchased (expressed as a ratio between the last in-production purchase and the out-of-production purchase), and time of the gap between purchases used as the candidate independent variables. The model itself would be determined by the statistical properties of the model when applied to the data. In this study, a ninety percent confidence level was used to test the significance of all models.

An example of the multiple variable linear regression model, with an explanation of terms, using two independent variables is shown as equation (2). BASIC language notation is used to present equation (2).

```
Y = A + B1*X1 + B2*X2                    (2)
```

Where:

Y = the OOPFAC,
A = the intercept,
B1 = the coefficient of the first independent variable,
X1 = the first independent variable,
B2 = the coefficient of the second independent variable,
X2 = the second independent variable.

The third model was learning curve theory with an adjustment for a break in production. This corresponded to a loss of learning which was to be estimated based on an analysis of breaks in production found in the data. Kankey provides a good introductory discussion of learning curve theory (13:16-19). The basic learning curve is shown in equation (3) using BASIC language notation (13:17).

$$Y = A*(X\hat{\ }B) \tag{3}$$

Where:

Y = the cost of the Xth unit,
A = the cost of the first unit,
X = the unit for which the cost is being estimated,
B = an exponent which is related to the slope of the curve and to the rate of learning.

Using the predicted cost of the item, it would be possible to estimate the OOPFAC indirectly using the learning curve model.

The fourth model was the regression model with adjustment for the quantity purchased in each year. The exact formula (linear or non-linear) was not determined in advance; but it was expected that the OOPFAC would increase with increasing gaps between the end of the acquisition phase and the first purchases in the support phase. Also, for any given part the OOPFAC was expected to increase when the quantity of items purchased in the support phase was much lower than the quantity purchased in the acquisition phase. The model was expected to have the form of a

multiple variable regression model, see equation (2), with acquisition unit price and quantity to be purchased as the independent variables. The dependent variable would be the OOPFAC.

The fifth model was time series analysis of data. This was proposed as a tentative position, and was to be explored only if the four forms of the model proposed above proved to be inadequate.

It should be noted that none of these methods were used to develop the original OOPFAC. In the original OOPFAC, the total price of the C-141 avionics suite based on the stock list prices from the support phase was simply divided by the price of the avionics suite obtained from the original production contract. No statistical analysis of the factor was prepared (18:1-2).

An additional potential problem is that items of different technology levels may have different OOPFACs. The ten year limit on data retrievals imposed by the J018 procurement history listings of multiple purchases should limit the items to be sampled to a consistently more modern level of technology.

Testing the Results of Analysis

All standard statistical tests such as F test, t test, Full/Reduced Model testing, and tests as required for outliers, heteroscedasticity, collinearity, and other

potential statistical problems were used to insure that the results of the research were statistically valid.

The decision rule for accepting or rejecting the statistical hypothesis was set at the ninety percent confidence level.

As the research progressed, the logic of the OOPFAC model(s) was reviewed by practicing cost estimators to insure that no unwarranted assumptions were made by the researcher and that the resultant model(s) were useful for their intended purpose.

IV. Analysis

Data Preparation

After receiving the J018 procurement histories from the five Air Logistics Centers (16; 17; 19; 20; 24), the stock number records were sorted into four sets of data. One group was prepared for each of the three WSCRS avionic WBS categories 1) Communication, 2) Instrumentation, and 3) Navigation. These groups are referred to as VC, VI, and VN respectively in this thesis, and each group contains avionic components used to perform the functions denoted by the category names. The fourth group was composed of 117 items whose stock numbers indicated that they should fall in the avionic group, but which gave incomplete indication as to which of the three categories they should be assigned. This fourth group is referred to as the VNVC group because the supply class indicated that the items in it should either fall in the navigation or communications groups of avionics. The fourth group was retained as supplemental data to test the existence of a single OOPFAC for avionics.

After the data were sorted, each stock number record was reviewed for completeness, and a number of records were discarded for reasons discussed in the following paragraphs. Table I shows the original data requested for each set of data, the actual number with available history,

and the loss of data points due to the item not having adequate history at the time of the analysis to determine purchase prices after a transition from the original acquisition phase to the support phase of the items life cycle. The items which did not have enough procurement history did not seem to be drawn from a particular supply class or type of item. Therefore, since they are not from any systematic subgroup of the data, it is assumed that their absence from the total data set will not bias the results. The usable data, although not a very large sample in terms of the total population of repairable aircraft parts, provided enough data points to compute statistics which would be valid.

TABLE I

Data Requested, Received, and Usable

Items	Data Subset			
	VC	VI	VN	VNVC
Requested	100	117	111	119
Received	92	115	107	113
Insufficient History	23	24	24	32
Usable	69	91	83	81

The next step in the analysis was to convert the raw data into a form which would be useful for developing an OOPFAC. The J018 Procurement History Reports (PHR)

contained much more information on each stock number than was used in this analysis. These data elements, such as contractor facility, shipment mode, unit of issue, were not used in the analysis because the basic use of the OOPFAC is in life cycle cost estimating, and it seemed illogical to develop a factor which would rely on knowing which contractor would be producing an item 20 years in the future. As a result, the only data elements used from the procurement history were the date of contract award, the number of units purchased, and the unit price of the item.

After the usable items were selected, the unit prices for each purchase, for each item, were adjusted to constant Fiscal Year 1986 dollars. The procedure is discussed in the methodology chapter.

Based on discussions with Dr. Jerry D. Hofmann, Chief of the Cost Estimating Branch, HQ AFLC, and Mary Lou Hoza, project officer for the Logistic Support Cost Model, the method for determining the actual OOPFACs from the data was determined (9). This procedure consisted of two steps.

First, the break between the original production phase and the support phase would be determined. The time available to complete the research did not allow for detailed individual analysis of the procurement program for each of the items contained in each of the four sub-sets of data; to overcome this problem decision rules were used to determine the change of phase points. Two decision rules

were used with the first rule used in preference to the second. The rules were: 1) One year or more with no purchases, and 2) A sustained drop in purchases by more than 50 percent from one year to the next. These rules were applied to each of the items with usable procurement history.

Second, the OOPFAC(s) for each item was computed using the average unit cost of the last buy before the change in phase and the average unit cost for each year in which purchases were made after the change in phase. This creates the possibility for more than one OOPFAC per stock number, and in fact this did occur for a significant number of items in the samples. Each OOPFAC occurrence was used as a data point in the following analysis steps, increasing the number of data points to the figures shown in Table II.

The researcher discussed the use of two different methods of computing the OOPFACs for analysis in this study with Dr. Jerry D. Hofmann, then Chief of the Cost Est·¬ating Branch, Directorate of Cost Analysis, HQ Air Force Logistics Command (9). Two alternative methods of computation were discussed: First, computing the OOPFAC by taking a weighted average of all purchases after the break between the acquisition phase and the support phase of the procurement cycle for each part; second, computing individual OOPFACs for each fiscal year in which an individual part was purchased in the support phase.

Each method had certain advantages which were considered before the final determination of the method was made. The first method, aside from being somewhat less cumbersome computationally, gave each stock number equal weight in the process of determining the OOPFAC for the data set. It also retained the randomness of the data sets which would increase the representativeness of the data during the analysis phase. The second method was more advantageous in that it gave more weight to the items which had been procured more often, and it retained the variability in the values of the individual OOPFACs which was visible in the raw data. Because it was felt that the items which were procured more often should be given more weight than the items which were procured less often and in order to maintain the variability of the data in the computation of variances and standard deviations, the second method of computations using individual OOPFACs for each fiscal year an item was procured was selected for use in this study (9).

TABLE II

Stock Numbered Items and OOPFAC Occurrences

	Data Subset			
	VC	VI	VN	VNVC
Usable Items	69	91	83	81
OOPFAC Occurrences	130	177	154	154

Univariate Analysis

The first true analysis step was to compute the mean and standard deviation of the OOPFAC for each of the four sub-sets of data. This was done using the SAS Inc, Univariate Analysis Procedure (PROC Univariate), as described in the SAS model documentation (21:1182-1191). The SAS documentation does not discuss the statistical formulae or provide any background material on the statistics which it computes; it only describes how to use the SAS software package to compute the statistics. For a discussion of the computation of the mean and standard deviation of a sample the reader is referred to Moskowitz and Wright (14:22-33). Other standard statistical texts will also contain adequate discussions of measures of central tendency and dispersion.

The OOPFAC for each of the four sub-sets of data was computed using five different weighting factors. The weighting systems were introduced into the analysis to allow for the different levels of effect on the estimate for the unit price of each item procured and for the number of each item procured. Out of many possible methods the five weighting methods used were:

1) Equal weight to each OOPFAC occurrence

2) Weighted by the cost of the last lot during the acquisition phase for the item (gives weight to the unit cost of each item and the quantity in the lot)

3) Weighted by the average unit cost of the last lot of the acquisition phase

4) Weighted by the cost of the support phase annual lot on which the actual OOPFAC is computed

5) Weighted by the average unit cost of the support phase annual lot on which the OOPFAC is computed

It should be noted that weighting systems 4 and 5 are based on the items which are being estimated using the OOPFAC; therefore, when the OOPFAC is used for estimating, these weights would not be available. Method two comes closest to the original OOPFAC computation method, which was to divide the avionic suite costs for the C-141 aircraft in the support phase by the suite costs in the production phase (18). This introduces the quantity per application (QPA) for each item in the avionic suite as a weight in computing the OOPFAC. Since the data set is not based on a single aircraft, but is a random sample from all aircraft, the QPA for each item is not available (it could in fact be different for each application, if the item has more than one application). Using the total quantity purchased gives an effect similar to the QPA but not identical.

Method Two should be used as the best of the proposed weighting systems. It is the best because it adjusts for the average unit cost of the item and the quantity procured. This gives a measure of the importance of each

item to the total Air Force spare parts procurement budget. A theoretically better weight would be to use weighting Method Four, but this would involve the use of circular logic when future procurements are being estimated. In that case, the OOPFAC would have to be estimated before the weights were developed to estimate the OOPFAC. So, even though Method Four has the better theoretical foundation, it is not useful from a practical standpoint. The reasonable solution is to use Method Two and to make the assumption that quantities purchased in the acquisition phase are proportional to the quantity purchased in the support phase. If the quantities purchased are proportional, the weightings from Method Two will have the same effect as the weightings from Method Four. Although this will not be true in every case, the assumption is a necessary working assumption given the present level of knowledge about the OOPFAC.

Table III shows the results of the univariate analysis of the four sets of data using the five weighting systems. Means and standard deviations are shown for each combination of data set and weighting method. In addition, the range of the OOPFAC and the number of OOPFAC occurrences are shown for each data set.

TABLE III

Univariate Analysis

Weighting Method	Data set VC	VI	VN	VNVC
Unweighted				
Mean	1.0107	1.0035	0.8031	0.9724
Std Dev	0.6955	0.3030	0.5199	0.4980
Production Lot Cost				
Mean	1.2451	1.1097	0.8389	1.0637
Std Dev	0.4177	0.3337	0.4002	0.5051
Production Unit Cost				
Mean	0.9786	1.0304	0.7598	1.0557
Std Dev	0.4010	0.3039	0.5307	0.5447
Support Lot Cost				
Mean	1.3038	1.0437	1.0940	1.1721
Std Dev	0.4669	0.2198	0.5174	0.4922
Support Unit Cost				
Mean	1.1429	1.1201	1.1305	1.3368
Std Dev	0.4390	0.3213	0.6408	0.6370
Range of Data				
High	6.26	2.43	3.04	2.80
Low	0.21	0.16	0.05	0.05
Number of OOPFAC Occurrences				
	130	177	154	154

Hypothesis Tests of Means

Of course, the statistics in Table III do not answer the question as to whether there is one OOPFAC or several OOPFACs for the avionic items in the Air Force inventory. To determine if one or more than one OOPFAC exists a statistical test must be conducted to determine the probability of a given level of difference between the means of the data sets. This test is discussed in Moskowitz and Wright (14:380-384), and other standard statistical texts. For the convenience of the reader, the formula is reproduced here using BASIC computer language notation, as equation (4).

```
Z = ((X1-X2) - (U1-U2))/((S1/N1)+(S2/N2))^0.5        (4)
```

Where:

```
Z  = the test statistic
X1 = mean of sample 1
X2 = mean of sample 2
U1 = mean of population 1
U2 = mean of population 2
S1 = variance of sample 1
S2 = variance of sample 2
N1 = number of data in sample 1
N2 = number of data in sample 2
```

In this case, the test is being used to test the null hypothesis that U1 - U2 = 0, that is that the population means for the two sample sets of data are the same. Therefore, in computing the test statistic all values are entered into the equation except that (U1 - U2) is treated as zero.

The resulting Z value is then compared to the values in the Standard Normal Distribution table to determine if the computed Z falls within the pre-determined range for accepting or rejecting the null hypothesis. A two tailed test is used in this case, and the pre-determined level of confidence is 90 percent. Therefore, a computed Z value between -1.645 and 1.645 implies that the population means are equal (with 90 percent confidence), and the null hypothesis is accepted. A computed Z which does not lie between -1.645 and 1.645 implies that the true population means of the two samples are not equal, in this case the null hypothesis is rejected.

Table IV contains the computed Z values for all combinations of the sets of data obtained for this study. An asterisk beside a number in the table indicates that for this occurrence the null hypothesis would be rejected, that is that the means are not equal. The values were computed using the Z test statistic formula and the statistics contained in Table III. Under each Z value, and in parenthesis, is the probability of obtaining the same or higher Z value by chance (p value). The reader may use this p value to make independent evaluations of the likelihood that the combinations of data sets yield the same OOPFAC values.

Table IV is in five parts; one part for each of the weighting systems for computing the OOPFAC. Because of its length, Table IV is on two pages.

TABLE IV

Hypothesis Test Z Values

Unweighted

	VC	VI	VN	VNVC
VC	----			
VI	0.111 (0.912)	----		
VN	2.805* (0.005)	4.203* (0.001)	----	
VNVC	0.522 (0.603)	0.674 (0.503)	-2.919* (0.004)	----

Production Lot Cost

	VC	VI	VN	VNVC
VC	----			
VI	3.050* (0.004)	----		
VN	8.323* (0.001)	6.618* (0.001)	----	
VNVC	3.313* (0.001)	0.962 (0.337)	-4.339* (0.001)	----

Production Average Unit Cost

	VC	VI	VN	VNVC
VC	----			
VI	-1.235 (0.219)	----		
VN	3.952* (0.001)	5.581* (0.001)	----	
VNVC	-1.371 (0.171)	-0.511 (0.603)	-4.828* (0.001)	----

Support Lot Cost

	VC	VI	VN	VNVC
VC	----			
VI	5.890* (0.001)	----		
VN	3.590* (0.001)	-1.121 (0.263)	----	
VNVC	2.310* (0.021)	-2.988* (0.003)	-1.357 (0.174)	----

Support Unit Cost

	VC	VI	VN	VNVC
VC	----			
VI	0.502 (0.617)	----		
VN	0.193 (0.849)	-0.182 (0.858)	----	
VNVC	-3.021* (0.001	-3.820* (0.001)	-2.833* (0.005)	----

Some of the Z values are within the range to accept the null hypothesis and others are not. Since many tests have been conducted we would expect some results to support the null hypothesis based purely on chance. As 30 tests have been conducted, on average three would support the null hypothesis purely by chance using the 90 percent confidence level.

One way to reduce the play of chance is to see how many combinations of data sets had test results in support of the null hypothesis under more than one weighting system. Table V shows a tally for each of the combinations of data sets supporting the null hypothesis. A value of three in Table V indicates that the null hypothesis was supported by three of the five weighting systems. A value of one indicates that the null hypothesis was supported by one of the weighting systems for that combination.

TABLE V

Null Hypothesis Tally

	VC	VI	VN	VNVC
VC	---			
VI	3	---		
VN	1	2	---	
VNVC	2	3	1	---

Table V shows that all of the combinations had at least one weighting system with a comparison where the null hypothesis of the difference could not be rejected. Since we would expect three such tests by chance at the 90 percent confidence level, the presence of 12 such tests results exceeds chance occurrence. However, this is inadequate support for the use of a single OOPFAC for all avionics since a majority of tests indicate that the OOPFAC for each data set is distinct at the 90 percent level. This is distinction is also supported because in five of the six tests using the production lot weight individual OOPFACs are indicated.

In the case of the weighting system closest to the original OOPFAC method, and most logically supportable since it acknowledges both the cost of the item and the number procured, that is the production lot cost weight; only one combination would be accepted as having the same means. This combination is the instrument group (VI) with the mixed avionics group (VNVC). Unfortunately, in this case there is a logical inconsistency between the statistical test and the classification of the items. Since neither the navigation nor the communication group test as having means equal to the instrument group it seems contradictory for a combination of navigation and communication to test as equal to the instrument group.

Looking at the individual OOPFACs for the VC and VN groups separately reveals that one is significantly higher than VI, while the second is significantly lower than VI. It is thus likely that the same type of items in the VNVC group may balance out resulting in a value of 1.06 which is not significantly different from the VI mean. The use of a single OOPFAC would run the same risk of averaging actual OOPFAC values for categories of avionics. Such a factor would be acceptable only if the proportion of items in the categories remained constant. Since these proportions vary by system, this makes an additional argument in favor of separate OOPFACs.

Two other tests of means need to be made to complete the univariate analysis. The method used to conduct these tests is discussed in Moskowitz and Wright, but may be found in any standard statistics book. The Z value computed by the formula is the basis for the hypothesis test to determine if the sample mean is equal to the postulated population mean. The same formula is used for both tests with only a change in the postulated value of the population mean.

The following formula is used in both cases (14:374-380). The formula is shown here in BASIC language format, as equation (5).

$$Z = (M1 - M2)/(S/(N)^{\wedge}0.5) \tag{5}$$

Where:

Z = the Z value being computed for the hypothesis test
M1 = the sample mean
M2 = the population mean
S = the sample standard deviation
N = the sample size

The first value tested was the probability that the mean of the OOPFAC for each data set is equal to one. If this is true, the OOPFAC exists but it is trivial since a factor of one has no effect on the estimating process. The second value tested was the probability that the OOPFAC equals 1.8, the factor developed in the original study. This is of interest since it will decide if the factor must be updated in cost estimating models. The last paragraphs in this section will address these two sets of tests.

Table VI shows the computed Z values for the two tailed hypothesis test that the OOPFAC is equal to 1.0, the Z value to accept the null hypothesis (that the OOPFAC is 1.0) is again the range from -1.645 to 1.645. Under each Z value the associated probability value is shown in

parenthesis, and each case where the null hypothesis was rejected (mean does not equal one) is indicated by an asterisk.

TABLE VI

Computed Z Values for the Test that OOPFAC Equals 1.0

Weight	VC	VI	VN	VNVC
Unweighted	0.1754 (0.865)	0.1537 (0.881)	-4.6999* (0.001)	-0.0878 (0.928)
Production Lot	6.6904* (0.001)	4.3749* (0.001)	-4.9955* (0.001)	1.5650 (0.119)
Support Lot	7.4188* (0.001)	2.6451* (0.008)	2.2546* (0.024)	4.3391* (0.001)
Production Unit Cost	-0.6085 (0.542)	1.3309 (0.183)	-5.6167* (0.001)	1.2690 (0.204)
Support Unit Cost	3.7114* (0.001)	4.9730* (0.001)	2.5272* (0.011)	6.5614* (0.001)

Remembering that we expect some of the tests will show that the OOPFAC is equal to zero by chance, the three pure groups seem to reject the hypothesis that the OOPFAC is one very strongly. The group of mixed communication and navigation items (VNVC group) fails to reject the null hypothesis for three of the five weighting systems including the production lot cost weighting method which is regarded as the most valuable. Therefore, not being able

to reject the null hypothesis the conclusion is that the VNVC has an OOPFAC equal to one. The other data sets reject the null hypothesis very strongly, supporting the hypothesis that the OOPFACs for them are not equal to one.

It is possible that the VNVC data set does not produce an OOPFAC which is not different from zero only because it is not possible to divide the data into the appropriate data sets. If the reader considers the values for the VN and VC data sets in Table III, Univariate Analysis, for the production lot cost weight, it will be noted that the mean of the VNVC data set falls about halfway between the means of the VN and VC data sets. The standard deviation of the VNVC data set is also larger than either the VN or VC data set standard deviation. This combination of statistics could indicate that since the VNVC data set is composed of both VN and VC Work Breakdown Structure (WBS) items its OOPFAC is close to one simply because it is not possible to assign the items to their correct WBS category.

The second set of hypothesis tests in this group tests to determine if the newly computed OOPFACs equal the original factor of 1.8. Again, the Z value test of means will be used, see equation (5). Table VII shows the computed Z values for this test with the null hypothesis being that the OOPFAC is equal to 1.8, and the alternative hypothesis being that the OOPFAC is not equal to 1.8. The range of values for accepting the null hypothesis remains

the same as for the test that the OOPFAC is equal to one (-1.645 to 1.645). Probability values are not shown for this table as all except one of the Z values are beyond the range of the common Z value tables (14:743-744). This means that all the differences are extremely strong and that the probability of their occurring by chance is less than one in ten thousand. All Z values are followed by an asterisk to indicate that the null hypothesis is rejected in every case.

TABLE VII

Computed Z Values for the Test that OOPFAC Equals 1.8

Weight	VC	VI	VN	VNVC
Unweighted	-12.9395*	-34.9728*	-23.7953*	-20.6230*
Production Lot	-15.1468*	-27.5295*	-29.8024*	-18.0900*
Support Lot	-12.1173*	-45.7776*	-16.9332*	-15.8310*
Production Unit Cost	-23.3551*	-33.6915*	-24.3236*	-16.9571*
Support Unit Cost	-17.0663*	-28.1528*	-12.9655*	-9.0238*

As Table VII shows, the hypothesis that the OOPFAC is equal to 1.8 is rejected for every data set and every weight combination. Nothing in this sample supports the original value of the OOPFAC.

Multivariate Analysis

In this section, an attempt will be made to use regression analysis to predict the OOPFAC for individual items within each of the four sets of data used in this study.

In order to limit the scope to both a reasonable amount of data and the most practical options for multivariate analysis, the four data sets will be evaluated for only the unweighted and the Production Lot Cost weighted cases. These two cases will be evaluated since they represent the two most significant possibilities for use in the Logistics Support Cost Model. The unweighted data will be evaluated since this represents the simplest possible model for predicting the OOPFAC. The Production Lot Cost weighting will be evaluated since it opens the model to the effects of the unit price of the item and the quantity of the item purchased; the two together provide a relative measure of the importance of each item based on its proportionate procurement cost to the total procurement cost of Air Force repairable spare parts.

The approach used to prepare the model will be the least squares regression technique. While a description of this technique is beyond the scope of this study, the basic mathematical method is to minimize the sum of the squared distances between each of the data points in the sample set and the regression line. For a rigorous description of the

mathematical technique the reader is referred to a standard text such as Neter, Wasserman, and Kutner (15:23-51).

For the purposes of this study, the independent variables which were evaluated are:

1) The ratio of the quantity purchased in the last year of acquisition to the quantity purchased in the year of support phase from which the OOPFAC was computed (referred to as RATIO in this study).

2) The number of years between the last acquisition purchase and the purchase from which the OOPFAC was computed (referred to as DIFFERENCE in this study).

Before preparing the regression analysis, the expected effect of the independent variables should be stated. As discussed earlier, the OOPFAC should increase as RATIO increases. This should be true since when the quantity bought in the acquisition phase is larger than in the support phase, we would expect, everything else being equal, that unit prices would be higher in the support phase because of the relationship of unit cost to volume produced.

Also, it would be expected that the greater the DIFFERENCE variable, the greater the OOPFAC, everything else being equal. This would be true because the longer the break in production the greater the loss of skill in producing the item.

These two independent variables were used in the modeling process to predict the OOPFAC, both as single estimators and in combination. This involved the use of the simple linear regression model (15:23-51), and the multiple regression model (15:226-242). The SAS Institute, INC. statistical package was used to compute the statistics used in this report. In particular the PROC REG procedure (22:655-709) was used for all the statistics discussed in the remainder of this section.

Table VIII shows the results of the simple linear regression model using the unweighted data and RATIO as the independent variable. For each of the four data sets, the table shows the predicted intercept, the predicted coefficient of RATIO, the T values for the intercept and coefficient, the probability values associated with the T values for hypothesis testing. Those statistics which are significant at the ninety percent level are indicated with an asterisk.

TABLE VIII

Regression Results: Unweighted Data, RATIO as Predictor

	VC	VI	VN	VNVC
Predicted Value				
Intercept	0.9324	0.9852	0.8173	0.9083
Coef of RATIO	0.0834	0.0064	-0.0082	0.0519
T values				
Intercept	13.986* (0.001)	42.182* (0.001)	17.990* (0.001)	17.920* (0.001)
Coef of RATIO	2.628* (0.010)	3.041* (0.003)	-0.809 (0.420)	2.034* (0.043)

As can be seen from Table VIII, the RATIO is a significant predictor of the OOPFAC for three of the four sets of data. The relationships also agree with the expected relationships so that they are logically valid as well as being statistically significant.

Table IX shows the results of the simple linear regression model using the unweighted data and DIFFERENCE as the independent variable. For each of the four data sets, the table shows the same information for DIFFERENCE as the independent variable as Table VIII showed for RATIO as the independent variable. Those statistics which are significant at the ninety percent level are indicated with an asterisk.

TABLE IX

Regression Results: Unweighted Data, DIFFERENCE as Predictor

Predicted Value	VC	VI	VN	VNVC
Intercept	1.055	1.076	1.104	0.995
Coef of DIFFERENCE	-0.014	-0.025	-0.075	-0.009
T values				
Intercept	8.305* (0.001)	23.984* (0.001)	14.163* (0.001)	13.207* (0.001)
Coef of DIFFERENCE	-0.402 (0.688)	-1.802* (0.073)	-4.477* (0.001)	-0.356 (0.722)

Table IX shows that DIFFERENCE is a significant predictor of the OOPFAC for two data sets of the four. However, the statistically significant relationships have a negative coefficient so that they do not meet the predefined criteria for a logical relationship.

Table X shows information similar to that shown in Tables VIII and IX. Table X expands to show the coefficients for both RATIO and DIFFERENCE in the results of a multiple linear regression computation. In addition, the multiple F value (and associated p value) are shown for each data set (14:542-546). The F value allows the significance of the entire equation to be tested and compliments the T values which are used to test the statistical significance of the individual terms of the

equation. Using the F value and T values in combination it is possible to test the significance of the equation as a whole and as a collection of parts.

Table X

Regression Results:
Unweighted Data, DIFFERENCE and RATIO as Predictors

	VC	VI	VN	VNVC
Predicted Value				
Intercept	0.925	1.045	1.107	0.910
Coef of DIFFERENCE	0.002	-0.021	-0.075	-0.005
Coef of RATIO	0.084	0.006	-0.004	0.052
F values	3.430* (0.0354)	5.858* (0.003)	10.033* (0.001)	2.054 (0.132)
T values				
Intercept	6.892* (0.001)	23.108* (0.001)	14.070* (0.001)	10.575* (0.001)
Coef of DIFFERENCE	0.064 (0.949)	-1.548 (0.123)	-4.397* (0.001)	-0.019 (0.985)
Coef of RATIO	2.587* (0.011)	2.886* (0.004)	-0.305 (0.715)	1.995* (0.048)

In Table X, both of the independent variables are significant in at least one of the four data sets, but the RATIO alone was as a more significant predictor than when it was used in combination with DIFFERENCE. DIFFERENCE is statistically significant but is not logically consistent with the predefined expectations. The results of the

unweighted regression analysis show that the two independent variables deemed most likely to be able to predict the OOPFAC were in fact able to predict values for three of the four data sets. However, DIFFERENCE did not predict the OOPFAC well either alone or in combination with RATIO because the statistically significant relationships which were developed using DIFFERENCE as the independent variable were not logically consistent with the theory of breaks in production.

The rest of this section will continue with the use of regression techniques to predict the value of the OOPFAC when the OOPFAC was constructed using the production lot cost as a weight. The techniques used are the same as for the unweighted data, and RATIO and DIFFERENCE will be the variables used to predict the weighted data's results. However, there is an additional statistical problem with using the production lot cost as a weight. Any weighting system which does not use a weight which is proportional to the reciprocal of the variance for each variable will not result in the best linear unbiased estimate. This may result in biased solutions to the regression equation (22:662). It is not certain that the estimates will be unbiased or the degree to which the bias may occur. In this context, this is merely a situation where caution is required, and in this case it is assumed that if bias is

occurring in the analysis it was so small that the results of the analysis are not significantly affected.

Table XI contains the results of regression analysis using RATIO as the independent variable. The contents of Table XI are the same as for the preceding three tables in this section. The asterisk beside the T values indicates that the relationship is statistically significant at the ninety percent level.

TABLE XI

Regression Results: Weighted Data, RATIO as Predictor

	VC	VI	VN	VNVC
Predicted Value				
Intercept	1.242	1.081	0.869	0.940
Coef of RATIO	0.001	0.004	-0.010	0.064
T values				
Intercept	29.480* (0.001)	40.417* (0.001)	25.056* (0.001)	15.914* (0.001)
Coef of RATIO	0.146 (0.884)	2.742* (0.007)	-2.268* (0.025)	2.844* (0.005)

The results of using regression analysis to predict the production lot cost weighted OOPFAC using RATIO as the independent variable show that three sets of data have significant predictors at the ninety percent level. However, since the OOPFAC would be expected to increase as

RATIO increased, only two of the predictors are logically valid as well as statistically significant.

Table XII shows the results of attempting to predict the OOPFAC, with production lot weights, using DIFFERENCE as the independent variable. Again, the asterisk indicates that the relationship is statistically significant at the ninety percent level. The data sets with significant statistical relationships and which meet the logical criterion are the VI and VNVC data sets.

TABLE XII

Regression Results: Weighted Data, DIFFERENCE as Predictor

	VC	VI	VN	VNVC
Predicted Value				
Intercept	1.340	1.231	1.047	0.714
Coef of DIFFERENCE	-0.039	-0.050	-0.062	0.123
T values				
Intercept	17.587* (0.001)	24.012* (0.001)	15.425* (0.001)	9.949* (0.001)
Coef of DIFFERENCE	-1.425 (0.157)	-2.695* (0.008)	-3.455* (0.001)	5.702* (0.001)

Using DIFFERENCE as the independent variable results in three data sets with statistically significant predictors. However, only one (for VNVC) meets the logical criteria. This may be a case where expectations based on historical experience are not realistic in terms of modern

manufacturing technology which have reduced the effect of loss of learning during production breaks because of increased automation (5:64,66).

Table XIII contains the results of using both RATIO and DIFFERENCE as independent variables in a multiple regression analysis. Table XIII shows the same information as Table X.

TABLE XIII

Regression Results:
Weighted Data, DIFFERENCE and RATIO as Predictors

Predicted Value	VC	VI	VN	VNVC
Intercept	1.354	1.201	1.041	0.630
Coef of DIFFERENCE	-0.042	-0.049	-0.055	0.117
Coef of RATIO	-0.003	0.004	-0.006	0.051
F values	1.057 (0.350)	7.547* (0.001)	6.958* (0.001)	19.906* (0.001)
T values				
Intercept	15.394* (0.001)	23.337* (0.001)	15.355* (0.001)	8.072* (0.001)
Coef of DIFFERENCE	-1.447 (0.150)	-2.702* (0.008)	-2.918* (0.005)	5.493* (0.001)
Coef of RATIO	-0.314 (0.754)	2.749* (0.007)	-1.381 (0.169)	2.488* (0.012)

Using the production lot weighting, RATIO and DIFFERENCE are both statistically significant for two data

sets. However, they are only logical predictors for the VNVC set. For all other data sets, either the relationships are not statistically significant (VC), they are not logical relationships (VN), or as in predicting the VI data set OOPFAC the significant independent variable (RATIO) which also meets the logical standard is an equally good predictor when used alone. This last trait in the data is often interpreted to indicate that collinearity is present in the data set.

To test for collinearity between RATIO and DIFFERENCE, the coefficient of determination was computed between RATIO and DIFFERENCE for each of the four data sets. The results of this computation are shown in Table XIV. Table XIV shows the coefficient of determination (14:501-504) for each of the four data sets, and the probability of obtaining a higher level by chance. The statistics were computed using the SAS Institute, INC., PROC ANOVA procedure (22:113-137).

As can be seen from the results there is a high level of correlation for three of the four data sets. The high level of correlation between RATIO and DIFFERENCE indicate that except for the VN data set collinearity might be a significant problem in preparing a model of the OOPFAC using these two independent variables. This problem has already been observed in the OOPFAC modeling attempts made as a part of this study.

TABLE XIV

Correlation between RATIO and DIFFERENCE

	VC	VI	VN	VNVC
Coef of Determination	0.6391	0.9778	0.0731	0.0712
p Value	0.0001	0.0001	0.2627	0.2060

The result of this section is that the two variables believed to be the best predictors of the OOPFAC have in fact provided mixed results. RATIO appears to be the most useful of the two independent variables with statistically significant and logical results in slightly over half of the cases considered in this paper. DIFFERENCE provided some statistically significant relationships, but these relationships did not meet the expected logical relationship, that is that the greater the break in production the higher the OOPFAC. On the other hand, most of the equations using RATIO also met the logical criterion that the higher the value of RATIO the higher the OOPFAC.

The VC data set which has the most collinearity appears to be the most difficult OOPFAC to predict from the existing data sets, but at the same time the VN data set which has the least collinearity is also not well predicted by the independent variables tested. However, determining

the extent that the inability to predict the OOPFAC has been caused by the observed collinearity will require additional research which is beyond the scope of this study.

V. Discussion and Conclusions

Discussion of the Results

The purpose of this study was to answer the question "Is there a statistically significant mathematical relationship between the price of the items in the acquisition phase and the price of the same items when they are purchased, as spare parts, in the operating phase of a weapon system's life?"

In the Analysis Chapter it was shown that such a relationship does exist for the four samples of data which were used for this study, and the values of the OOPFAC with their associated standard deviations were shown in Table III. The various weighting methods were discussed, and the production lot cost method was considered to be the most valuable since it reflected both the quantity of the item purchased, the unit price, and would be available at the end of the acquisition phase for use in estimating the operating phase costs. However, hypothesis testing showed that for the mixed avionics set of data (the VNVC data set) the OOPFAC did not meet the predefined standard for statistical significance when tested to see if the value differed from 1.0, and in this case the solution was trivial.

The OOPFACs developed from the four sample sets were then tested to determine if the OOPFAC currently used (the

original factor, which is 1.8) was supported by the more recent data. In every case, for every weighting system, the null hypothesis was rejected indicating that the OOPFACs developed from each of the four data sets were different from the original factor. In many cases the computed Z values for the test indicated that the difference was significant at greater than ninety nine percent level of statistical significance.

Statistical tests were made to determine if the four data sets should be represented by a single OOPFAC or by individual OOPFACs, one for each data set. Although the results of these tests are not conclusive, the majority of the tests indicate that the data sets have individual OOPFACs.

Five potential models for the OOPFAC were discussed in Chapter III for evaluation during the analysis phase of the study. The first model was the two variable linear regression model. The results of testing this model with the independent variables RATIO and DIFFERENCE are discussed in detail in Chapter IV, Multivariate Analysis Section. Using this model showed that RATIO provided statistically significant and logical results in slightly more than half of the cases tested. DIFFERENCE was not a very good predictor because while it did produce statistically significant results, it did not produce logical results in the majority of the cases tested.

The second model discussed was the multiple variable linear regression model. The results of this modeling technique are also discussed in Chapter IV, Multivariate Analysis Section. The results of this model were that in only one case were the two independent variables statistically significant and logically supportable in the same model. This implies that the two variable models should be preferred to the multiple variable models since most of the independent variables show stronger relationships in the two variable models than in the multivariate models.

The third, fourth, and fifth models were not evaluated in this study due to the data not being directly usable for these methods. However, they remain valuable techniques and are recommended for use in future studies.

The basic results are that the OOPFAC does exist. Individual OOPFACs are required for different types of avionic items. The statistical tests indicate that the original factor is not representative of the current samples for four different groups of avionics items, and that the original factor should be replaced with more current factors. The last basic result is that the OOPFAC was not adequately predicted by either the length of the break in production between the acquisition phase and the operating phase purchases, or the relative number of items purchased in either phase.

Of major concern is the cause for the difference in OOPFAC values between the original study and the current study. One major cause is the difference in study methodology. The original study was based on a convenience sample of items from a single aircraft (18), while the present study was based on a random sample of items from the entire Air Force family of aircraft. This is the most likely cause for the difference.

Other causes for the difference in values could be less direct, but be caused by actual changes in the relationship of prices. Four possible effects are discussed in the following paragraphs.

First, programs such as PACER PRICE and ZERO OVERPRICE could be having an effect on actual prices paid by the Air Force. This effect would be caused by the increased competition among vendors and better monitoring of prices by Air Force personnel.

Second, the adjustment for inflation could cause different results at different times. The original study was prepared in a period of high inflation; while the current study was prepared in a period of much lower inflation. Baumgartner states that "The OSD escalation indices used for budgeting purposes were very low compared to actual escalation experienced" (4:32). If the actual inflation was higher than adjusted for by the price indices, in the earlier study, the OOPFAC would be higher

than if true inflation measures were used. In a period of high inflation, as when the original OOPFAC was prepared, this could have a noticeable effect.

Third, the actual characteristics of the items included in the sample could be changing over time. At the time of the original study, avionics included fewer integrated circuits than at present. Over the past ten years the cost of integrated circuits has fallen every year as production techniques have improved and volume has risen. If the cost of component parts were falling, this would tend to hold the price of items down even if there was general inflation. The decrease in the cost of the component parts of each of the items sampled could also compensate for all or part of the increase in costs caused by breaks in production or inefficient production rates.

Fourth, newer manufacturing techniques such as CAD/CAM may be reducing the fixed set up component of the cost of the items. Examples now include factories such as Allen-Bradley, Inc.'s industrial control plant which can produce a batch of one at the same cost per unit as a batch of one hundred (5:64). This would reduce the impact of breaks in production and small production quantities on the unit cost of parts leading to a reduction in the OOPFAC as manufacturing technology improves.

Implications for Cost Estimating

The most immediate implication for cost estimating is the need to officially update the OOPFACs used in estimating operating support costs for aircraft and missiles in the Air Force. The difference in values of the various OOPFACs, and the difference between the OOPFACs developed in this study and the original OOPFAC, is such that there could be large differences in Replenishment Spares estimates based on OOPFACs which were incorrectly applied.

For example, the recently completed Independent Cost Analysis of the C-17 transport aircraft used the traditional 1.8 OOPFAC. The estimate of the C-17 Replenishment Spares cost was $1,433.6 million, in Fiscal Year 1984 dollars (10). If an OOPFAC of 1.245, the highest computed OOPFAC using the last acquisition lot as the weight, had been used in preparing the estimate; the estimate would have been $991.6 million. This represents a difference of $442.0 million over the life of the program.

The major area of impact will be in the Logistics Support Cost (LSC) Model which now allows for only a single OOPFAC to be applied to all items (2:17). The LSC model will require revision to allow for the use of more than one OOPFAC. At present four factors have been developed, but provision should be made for the use of more than four OOPFACs in the model, as future studies will be required to

determine if there are non-trivial OOPFACs for other than avionics items and if additional OOPFACs are required for sub-groups of avionics items other than the WSCRS WBS avionics groups.

Any budgetary estimates which were prepared using the OOPFAC should also be revised to reflect the new factors. All future cost estimates should use the new factors whether prepared for use in the budget or for another purpose. However, since the OOPFAC was used primarily in preparing Independent Cost Analyses (18), the impact in this area should be minimal.

Conclusions, with Recommendations for Further Study

As discussed earlier in this chapter the concept of the OOPFAC has been substantiated and the updated values have been computed for the four sample sets of avionic data collected for this study. It is logical to use the three OOPFACs which were developed from the homogeneous data sets for estimating spare parts prices in the support phase of a system's life cycle. To repeat from Table III, those values are:

1) For communications items, 1.25
2) For instrument items, 1.11
3) For navigation items, 0.84

The use of these updated factors should improve future life cycle cost estimates for Air Force aircraft and

missiles. There may also be some application as default factors for use in estimating Air Force ground electronic systems.

The most important conclusion, other than the answer to the study question, that can be drawn from this study is the need to review and update all cost estimating factors on a regular basis. As the general economic climate changes and as the technology of Air Force systems changes all factors will become out of date over a period of time. Only a systematic program to update all important cost estimating relationships will ensure that high quality cost estimates are prepared.

As areas for future study, the following topics should be considered:

1) Determine the causes of changes in the value of the OOPFAC. This study computed the univariate statistics for the OOPFAC, but the attempts to predict the OOPFAC for individual items were only marginally successful. More work needs to be done in this area.

2) Investigate the value of the OOPFAC for types of items other than avionics. This study evaluated the OOPFAC for four groups of avionic items; future studies should look at the OOPFAC for mechanical, electrical, hydraulic, and other types of Air Force items.

3) Investigate the potential OOPFAC values for those items especially developed for the Air Force (or perhaps

Department of Defense) and those commercial items purchased "off the shelf" for Air Force use. This study did not collect data to draw this distinction, but different factors may be required for accurate estimating.

4) Investigate the reasonableness of the assumption that the quantity of an item purchased in the acquisition phase will be proportional to the quantity of the item purchased in the support phase. For additional information, see the discussion on methods of weighting in the Univariate Analysis Section of Chapter IV.

Appendix: Sample Data and Computations

This appendix is composed of three parts. First, an explanation of the basic data source listing, the process of converting the data to the data worksheets (including example computations), and an explanation of the data worksheet. Second, an example of a data worksheet. Third, an example of the basic data source listing annotated to show the major data elements.

For the example computation an avionic navigation item was chosen. This item was Federal Stock Number 6605-00-111-8047BJ, a frequency reference readout device purchased by Sacramento Air Logistics Center. The item itself was chosen because it shows the basic decisions and computations which had to be made in order to prepare the data for use in the statistical analysis.

The first step in preparing the data was to obtain the Daily Procurement History Report (DPHR) for the item. A copy of the DPHR for our example is included as Table XVI. The DPHR was obtained using an on-line computer process to access the J018, Contract Information Data System, automated data base. The date of processing is indicated in the upper right hand corner of the report, and the report contains all records for all purchases of the specified item for the ten years preceding the date of the report. Three elements of data were obtained from the

DPHR, contract award date, contract line item quantity, and the unit price. The columns which contain this data are marked with large arabic numbers 1, 2, and 3, respectively.

As can be seen from the sample report, many elements of data are contained in the DPHR which were not used in this study. Since the OOPFAC is a generic factor which is used to estimate the cost of aircraft and missile parts, the contractor specific data was not used in estimating the OOPFAC. Also, such data elements as the unit of purchase (unit of issue) were not addressed in the study because they were not expected to have an impact on the OOPFAC.

The first step of the data collection was to prepare a worksheet for each stock number in the four sample sets. Next the three data elements listed above where transferred to the worksheet. One set of the three data elements for each contract award date was transferred so that the worksheet contained a limited version of the DPHR. For those contracts with multiple contract awards on the same date, the data for contract line items was consolidated to reduce the computational workload. The three data elements were recorded in the three left-most columns on the worksheet, and the columns were labeled Date, Quant(ity), and Actual Cost respectively. In the example, there are eight contract award dates so that eight lines of data are entered on the worksheet.

The next step in the data preparation was to convert the actual cost of the item to a cost in a constant price level. The method used for this computation was to record the Inflation Factor (11) in the the column of the same name on the worksheet. A danger of misinterpretation was possible in selecting the correct inflation factor, and an additional computation not shown on the worksheet was needed. This is because the contract award date is shown as a Julian date using a calendar year basis and the Inflation Tables are prepared for Fiscal Years. Therefore, the Julian equivalent of 30 September had to be determined for each year so that the inflation factor could be determined. Weighted inflation indices were used since the actual date of production for the parts was unknown. The weighted indices incorporate the average outlay pattern for funds as well as the changes in price level so that both problems were adjusted for in the same computation. Then, the actual cost was multiplied by the inflation factor to obtain the Adjusted Cost which was entered on the worksheet.

At this point, the break between the acquisition phase and the support phase was determined for each item using the decision rules listed in the Data Preparation Section of the Analysis Chapter. For this example, there is a one year gap in purchases between the contract awards of 82022 and 83075, and between 83075 and 84179. A sub-rule (not

recorded in the main text of the thesis) of this decision rule was that if two possible break points occurred in the data, then the later point would be chosen in order to ensure that the acquisition phase was in fact complete. In this case the heavy horizontal line indicates that the break between 83075 and 84179 was chosen to represent the break point.

The next step was to compute the weighted average cost of the last acquisition year purchase. In this case, there was only one purchase so the Quant(ity) was copied to the Units column and the Adjusted Cost was copied to the Weighted Average Cost column.

Following the computation of the acquisition unit cost, the individual item OOPFAC for each Fiscal Year during the support phase was computed. In the example, there are two years with data in the support phase, and each year has two purchases. Therefore, it is necessary to compute a weighted average cost for each year. The weight is the number of parts purchased at each price. The number of items for the year is entered in the Units column and the cost is entered in the Weighted Average Cost column.

The final step on the worksheet was to compute the OOPFACs. This was done by dividing the Weighted Average Cost for each Fiscal Year in the support phase by the Weighted Average Cost for the last year in the acquisition

phase. After the values were computed, they were entered in the FY OOPFAC column at the right of the worksheet.

After the worksheet was complete the data was transferred to data files on the AFIT Classroom Support Computer (CSC) for statistical processing. The statistics used in this report were then computed using the SAS Institute, INC, statistical analysis package, as discussed in Chapter Four.

TABLE XV

Sample Worksheet

National Stock Number: 6605 00 111 8047BJ

Noun: Freq Ref Re

Air Logistics Center: Sacramento ALC

Date	Quant	Actual Cost	Inflation Factor	Adjusted Cost	Units	Weighted Average Cost	FY OOPFAC
81029	6	$3430	1.182	$4054			
81348	10	$4157	1.124	$4672			
82022	8	$4157	1.124	$4672			
83075	8	$7087	1.054	$7469			
84179	5	$6634	1.001	$6640			
84272	4	$5080	1.001	$5085	9	$5949	0.796
84300	6	$4480	0.962	$4310			
85051	14	$3311	0.962	$3185	20	$3523	0.472

TABLE XVI

Sample Daily Procurement History Report

[illegible] DAILY PROCUREMENT HISTORY REPORT 10:11:47 AM 4/03/85

BUYER- AJM REPLENISHMENT SPARE NSN: 6605001118047BJ — NOUN: [illegible] — AUTH METH CODE: 3H — STD PRICE: $3,245.77

PREV NSN: — PR/MARK LT QTY — UNIT OF ISSUE EA

PIIN MFG CD MFG NAME	SPIIN	CLIN	AWARD DATE	[illegible]	CONTRACT L/I QTY	PURCH UNIT	1ST ART	I I	TYPE CONT	SOL	USE REC	TYP PUR	PRI	ADV NEG	FOB	PKG EVAL	UNIT PRICE
[illegible] 94756 ROCKWELL INTL CORP,ELECTRONIC SYS	[illegible]	0001	[illegible]	AJM	6	EA		C	J	1	1	2	R	16	S	G	$3,430.0000
F04606[illegible] 94756	[illegible]	0001	81346	AAJ	10	EA		C	J	1	1	2	R	16	S	J	$4,157.0000
F04[illegible] 94756	[illegible]	0001	82022	[illegible]	7	EA		C	J	1	1	2	R	16	S	J	$4,157.0000
F04[illegible] 94756	[illegible]	0001	83075	AAJ	8	EA		C	J	1	1	2	R	16	S	J	$7,087.0000
F04[illegible] 94756	[illegible]	0001	84179	[illegible]	5	EA		C	J	1	1	2	R	16	S	J	$6,634.0000
F04[illegible] 94756	[illegible]	0001	84272	AAJ	4	EA		C	J	1	1	2	R	32	S	G	$5,080.0000
F04[illegible] 94756	0001	0001	84300	AAC	6	EA		C	J	1	1	2	R	16	S	J	$4,480.0000
F04[illegible] 94756	[illegible]	0001	85051	[illegible]	14	EA		C	J	1	1	2	R	16	S	G	$3,311.0000

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This investigation reviewed the statistical significance of the Logistics Support Cost (LSC) Model Out of Production Factor (OOPFAC) which is used to compute aircraft and missile spare parts costs during the support phase of a weapons systems life cycle. The review was composed of two major areas. First, the review computed statistics for four groups of avionic spare parts to determine if there is a single OOPFAC or if multiple OOPFACs were required for estimating. Although not totally conclusive, the results indicated that more than one OOPFAC should be used for cost estimating.

Second, the OOPFACs computed from recent data were compared using statistical tests to the original OOPFAC developed over seven years ago. The statistical tests rejected the use of the original factor, and the OOPFACs computed as part of this investigation were statistically different, by wide margins, from the original factor. As a result of the investigation, the OOPFAC should be updated in all Air Force cost estimating models to incorporate the newly computed factors.

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